VERITAS Deep Observations of the Dwarf Spheroidal Galaxy Segue 1

arxiv : 1202.2144

OKC-DM 2012/03/13

Christian Farnier

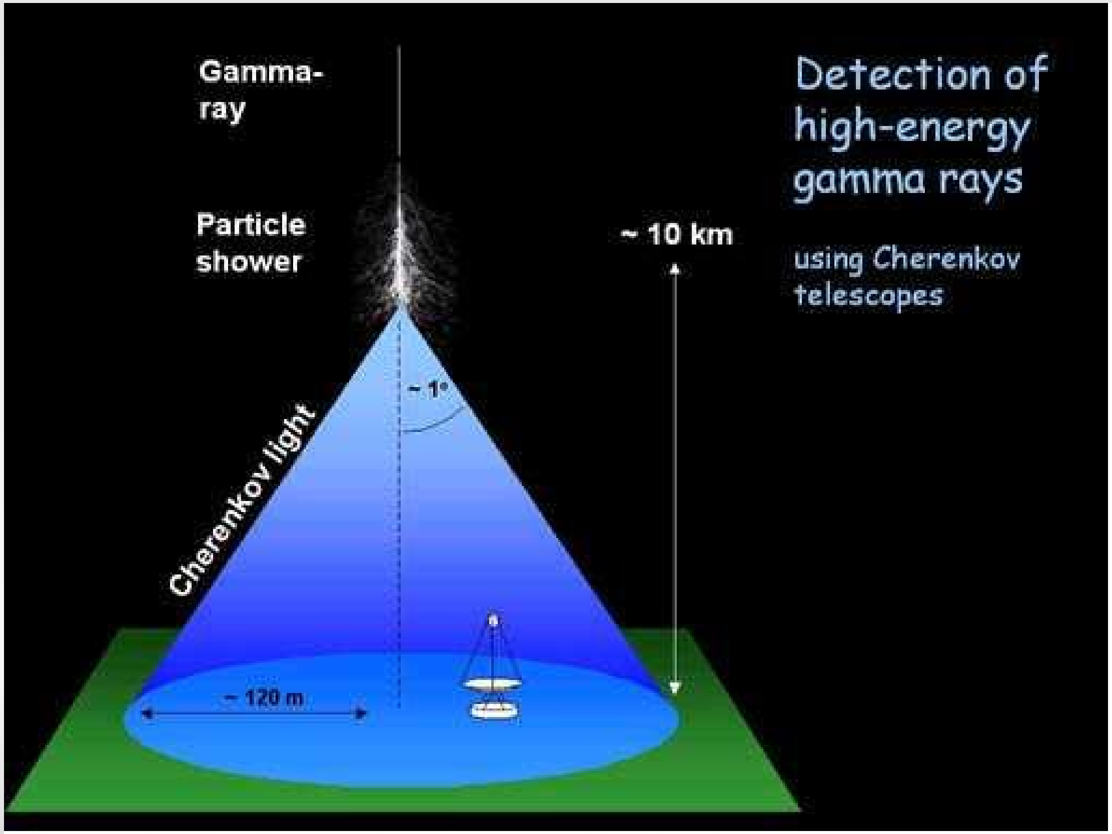
OUTLINE

- IACT / VERITAS reminder
- dSph – Segue 1
- VERITAS observations
- DM bounds

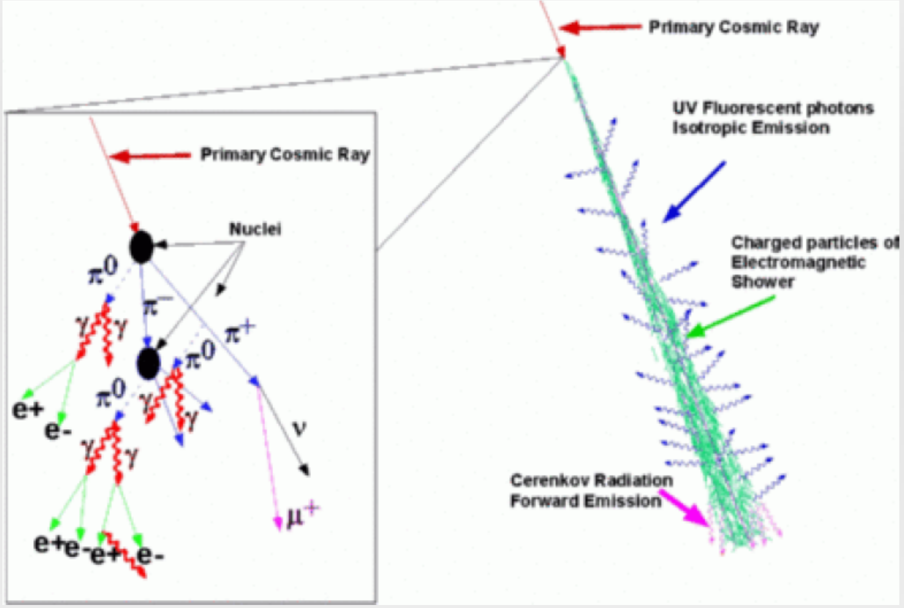
Imaging Atmospheric Cherenkov Telescope (IACT) principle

A high energy gamma-ray (or charged cosmic-ray) entering the atmosphere interacts with its atoms.

It produces a shower of secondary particles travelling @ v>c/n which creates a dim cone of Cherenkov light for a very short duration.



Credits : W. Hofmann

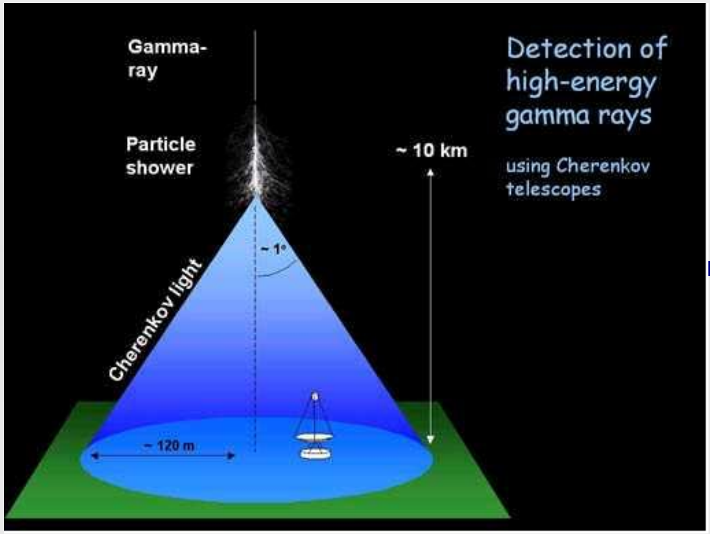


It is possible to observe such showers with large collection area mirrors and a fast camera put in their focal plane.

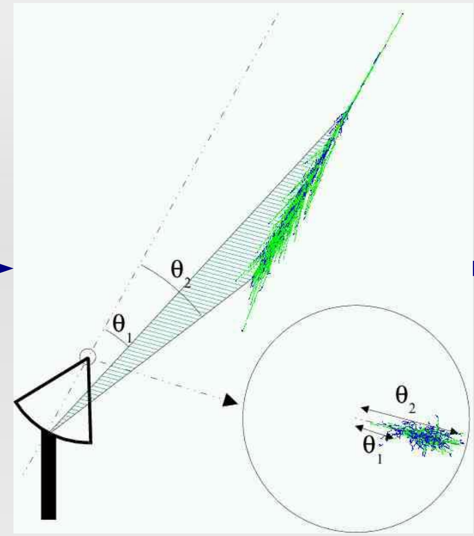
IACT experiments have to deal with background from :

- the night sky (stars, Moon, …)
- Charged cosmic rays (CCR) with a rate x10^5 times higher than the brightest TeV gamma-ray source.

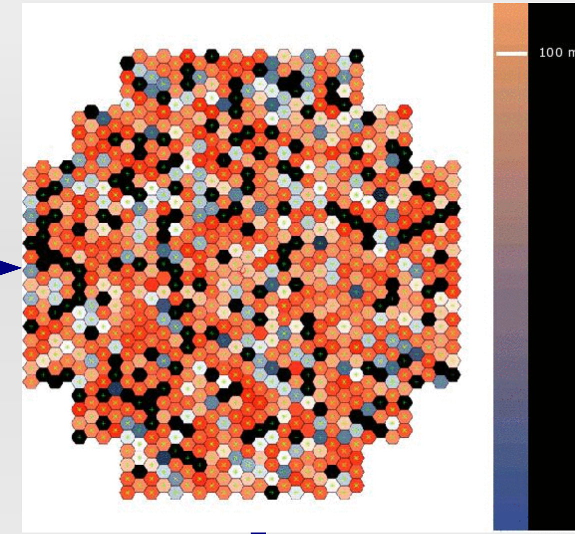
IACT principle (cntd)



Cherenkov photons production.



Shower development recorded in the focal plane.



Ultra fast (~10ns) acquisition camera.

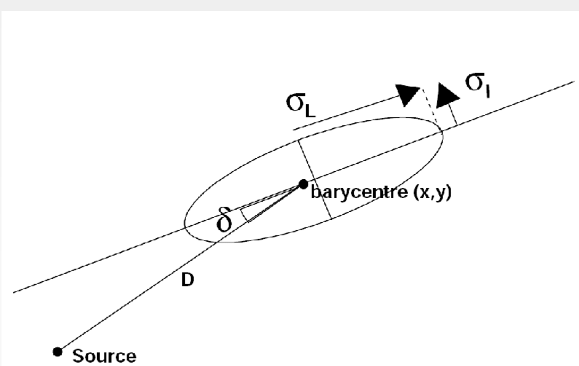


Image parameters reco. (direction, energy)

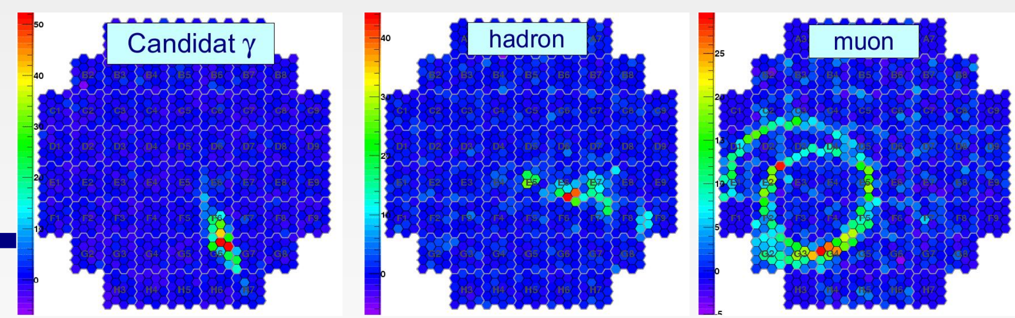
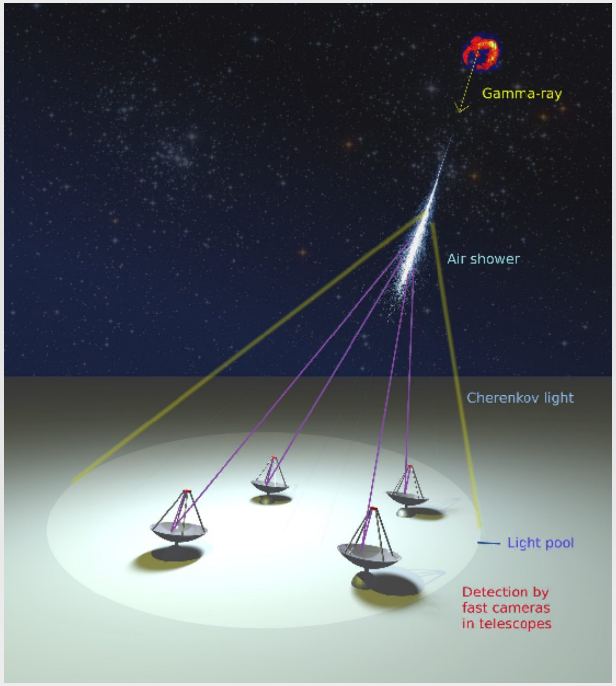
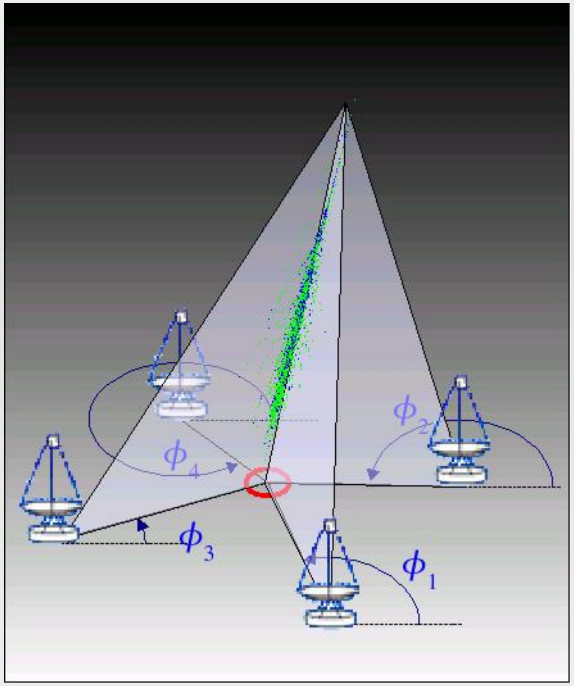


Image based event selection / background rejection.

IACTs - Stereoscopic system



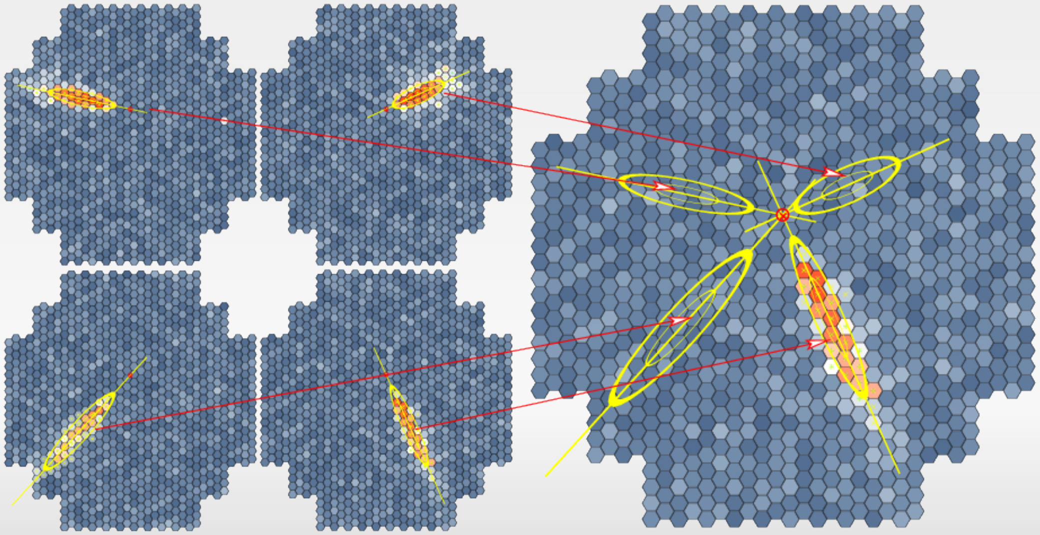


In the current experiments, up to 4 IACTs are put together, allowing to observe the same shower from several point of view.

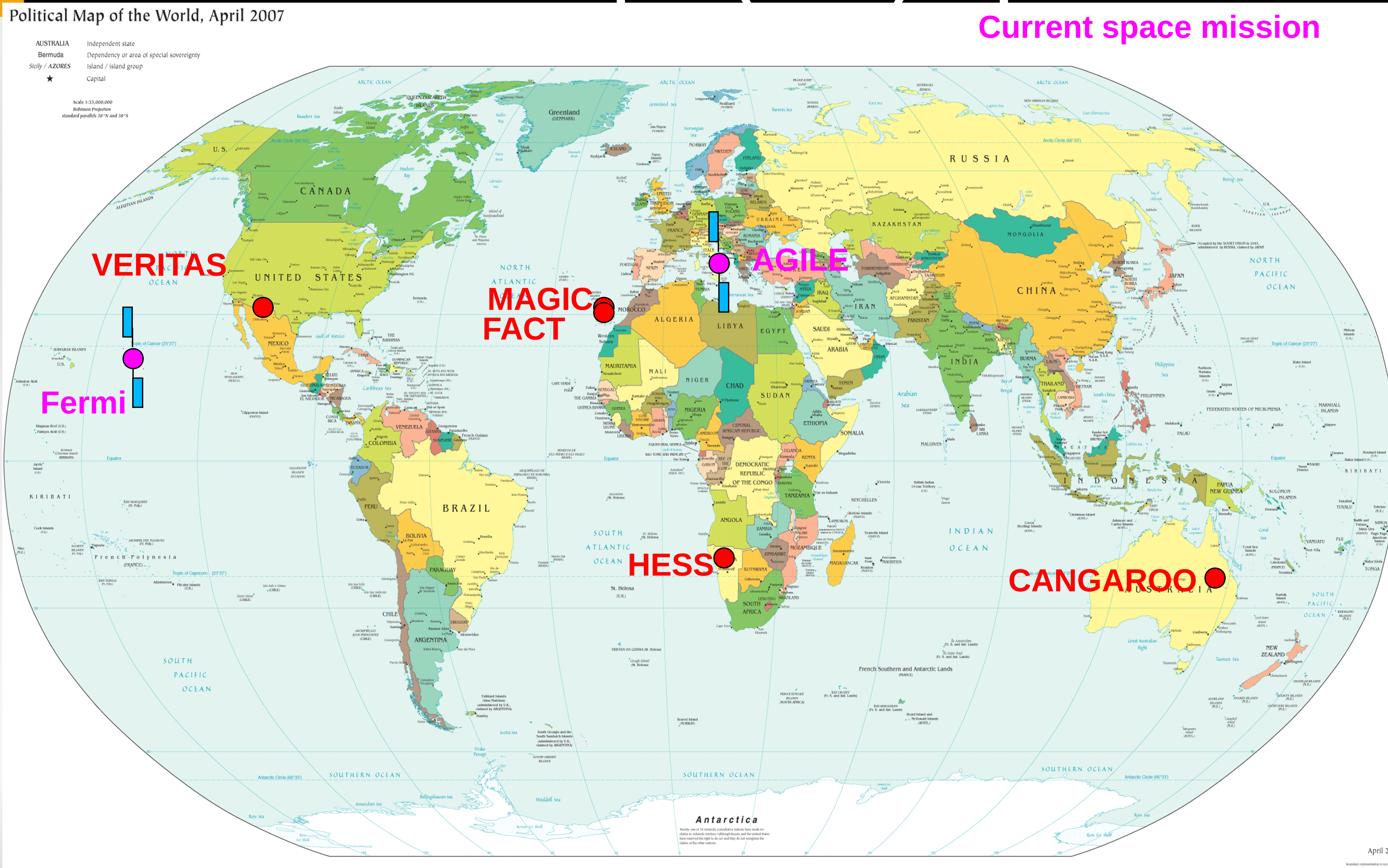
Advantages :

- Improved bckg rejection (muons)
- Incoming direction degeneracy dispelled
- Improved angular resolution
- Improved energy resolution

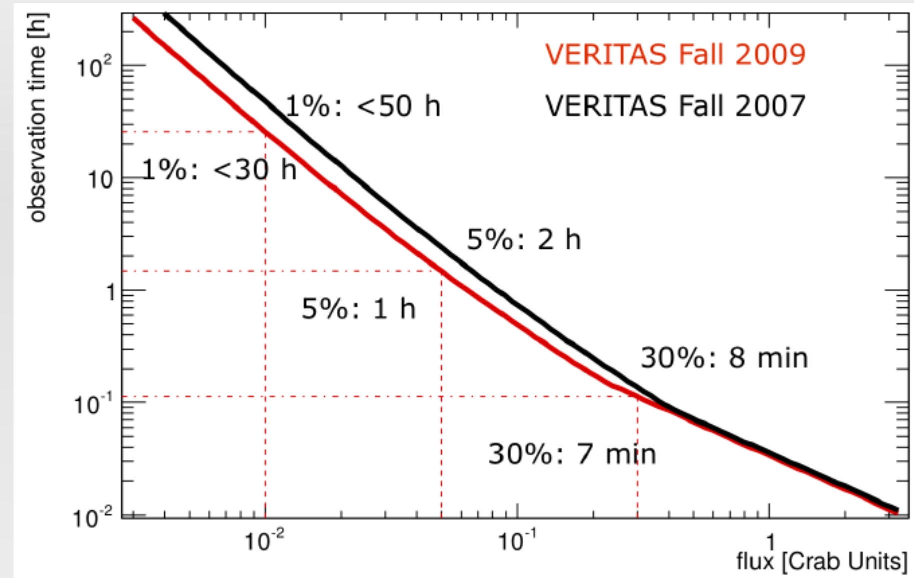
+ new shower reconstruction algorithms developped based on intrinsic 3D shower properties.



Census of relevant Imaging Atmospheric Cherenkov Telescopes (IACT) experiments



VERITAS



499 PMTs/camera

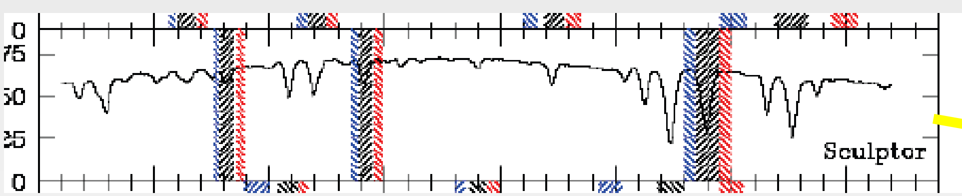
Aeff ~ 10^5 m^2

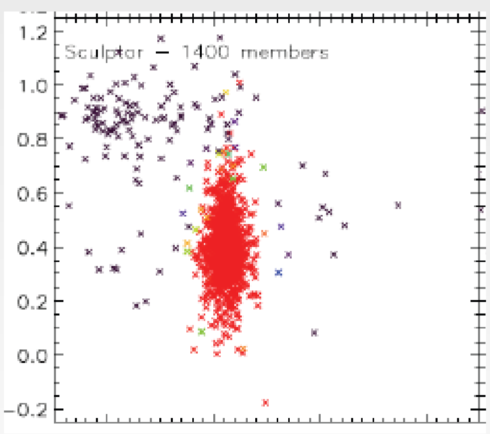
$\delta E/E$ ~ 15-20 %

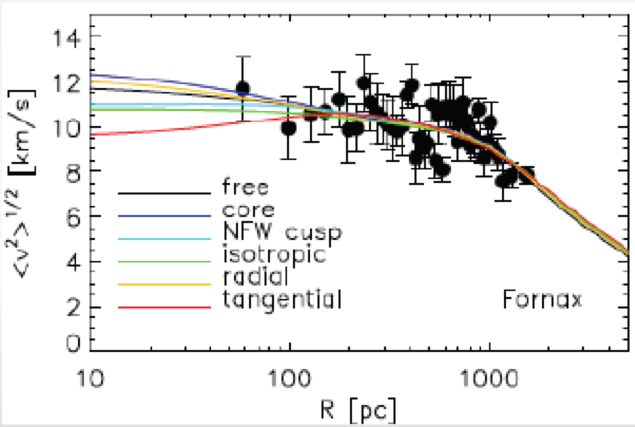
$\delta\theta$ ~ 0.1deg/event

Why dwarf galaxies ?

- DM dominated (M/L ~ 10 – 100)
- Satellites of the Milky-Way → nearby (~100 kpc)
- Low background (ordinary matter content very low)
- Stellar velocities can be used to measure DM density (error can be propagate to particle constraints)

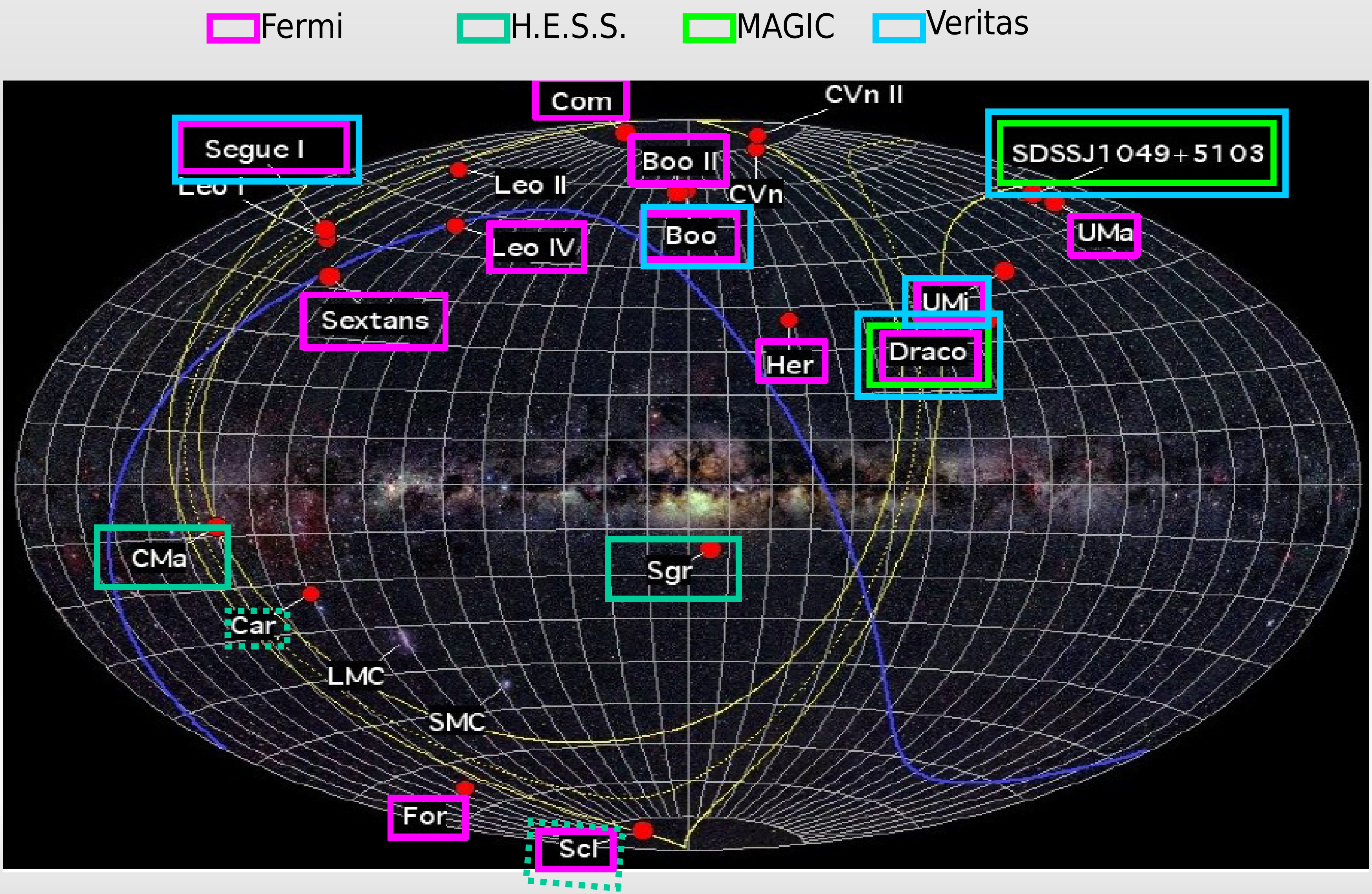






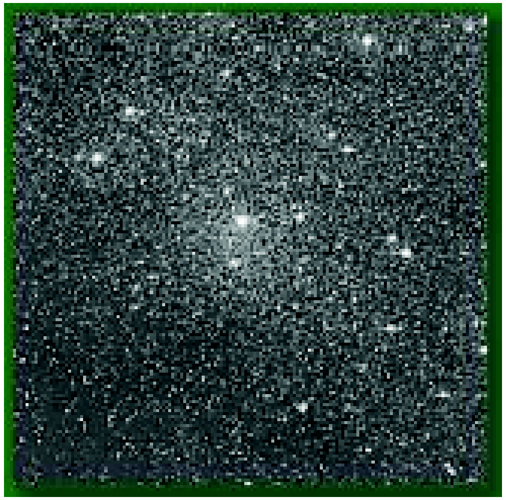
Results from dwarf spheroidal galaxies

Dwarf galaxies probed in gamma-rays as in 2011



Segue 1

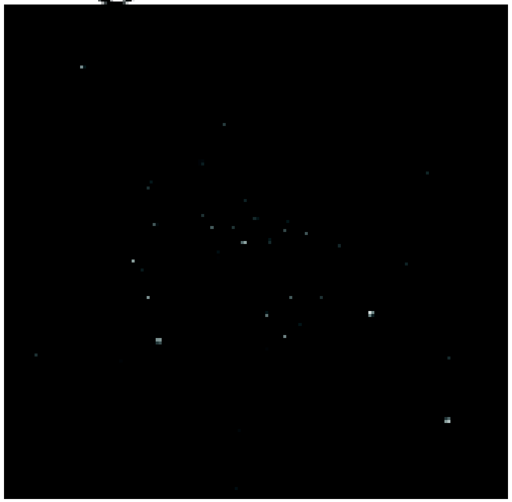
Draco (discovered 1954)



data on >200 stellar velocities

classical dwarf

Segue 1 (discovered 2006)



New stellar data is being analyzed (~65 stars)

[Simon et. al.]

ultra-faint dwarf

γ, ν flux $\propto \mathcal{L} \sim \int \rho^2$ determined from stellar velocities

Current analysis suggests $\mathcal{L}_{\mathrm{Segue1}} \gtrsim \mathcal{L}_{\mathrm{Draco}}$

However, this is preliminary and analysis is still ongoing!

Neelima Sehgal, KIPAC

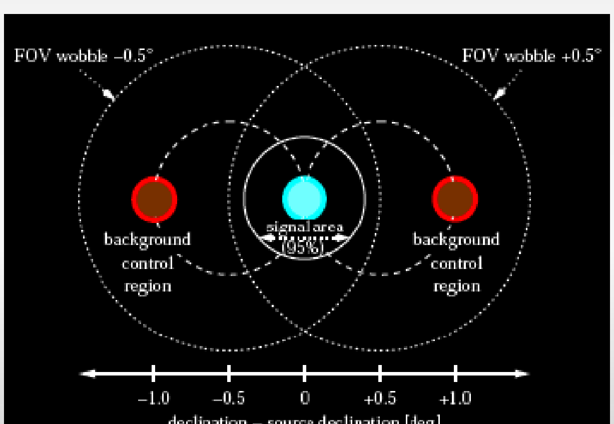
VERITAS observations

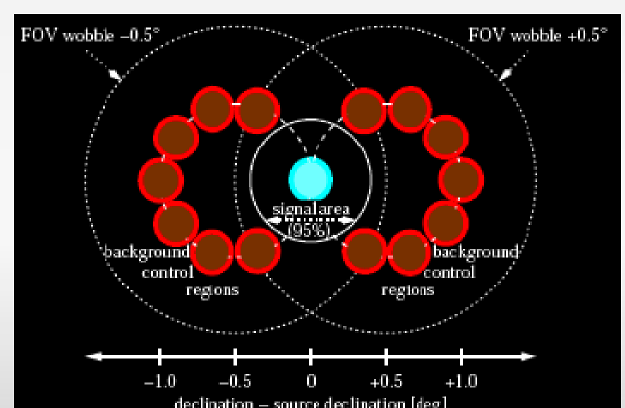
- Observations between Jan. 2010 and May 2011

  → total exposure after quality selection and dead time correction : 47.8h

- Mean zenith angle : 20deg (important for low E_{th}=170GeV / E_{th}=300GeV after additionnal cut to account for E bias)

- Wobble observations (0.5 deg offset)
  Increase the number of OFF regions → reduce the bckg systematic uncertainties ($N_{\gamma} = N_{ON} - \alpha x N_{OFF}$)



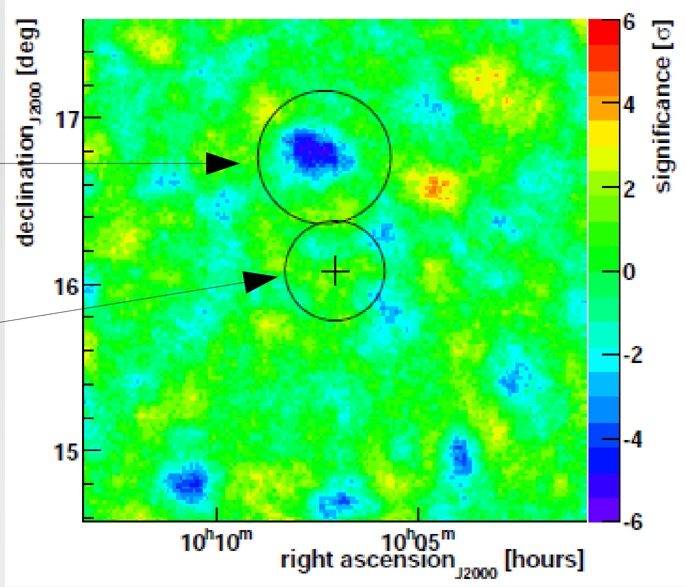


VERITAS observations - cntd

Significance map

η Leonis star region

ON source region



N_{ON} = 1082
N_{OFF} = 12479
T_{ON}/T_{OFF} = 0.084

			Li & Ma	Rolke
Live time (min)	E_{min} (GeV)	$N_\gamma^{exc}(E \geq E_{min})$	Significance	$N_\gamma^{95\%\,CL}(E \geq E_{min})$
2866	-	30.4	0.9	135.9
2866	300	31.2	1.4	102.5

Flux upper limits

- Flux UL are based on the number of accepted events, the effective area and the assumed spectral shape :

$$N_\gamma(E \geq E_{min}) = T_{obs} \times \frac{\int_{E_{min}}^{\infty} \mathcal{A}_{eff}(E) \frac{dN_\gamma}{dE} dE}{\int_{E_{min}}^{\infty} \frac{dN_\gamma}{dE} dE} \times \Phi_\gamma(E \geq E_{min})$$

- Integral flux ULs for different spectral index value in case of a power-law spectrum :

$$\frac{dN_\gamma}{dE} \propto E^{-\Gamma}$$

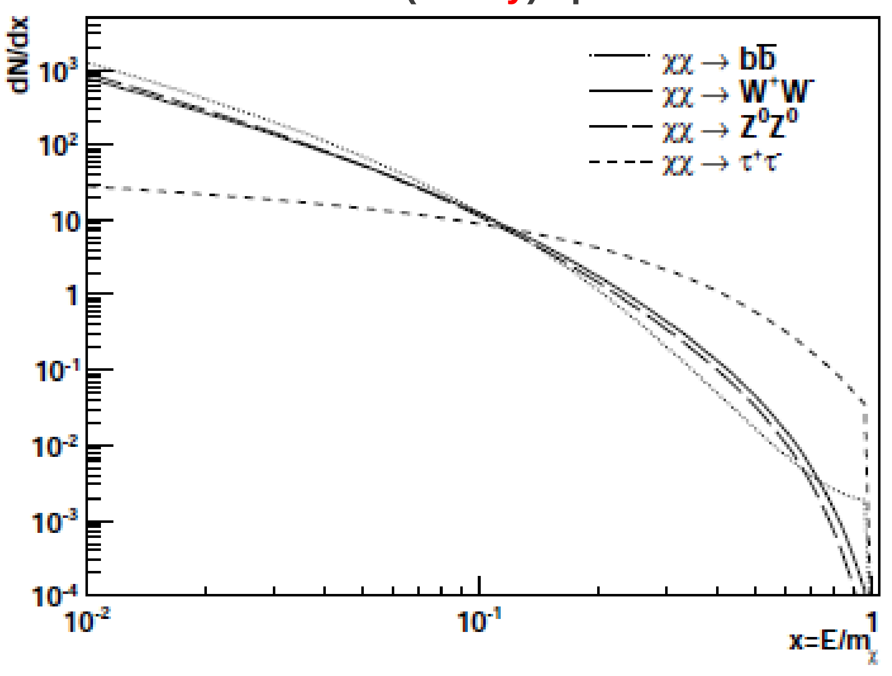
Spectral index Γ	$\Phi_\gamma^{95\%\,CL}(E \geq 300\,GeV)$ $[10^{-13}\,cm^{-2}\,s^{-1}]$
1.8	7.6
2.2	7.7
2.6	8.0
3.0	8.2

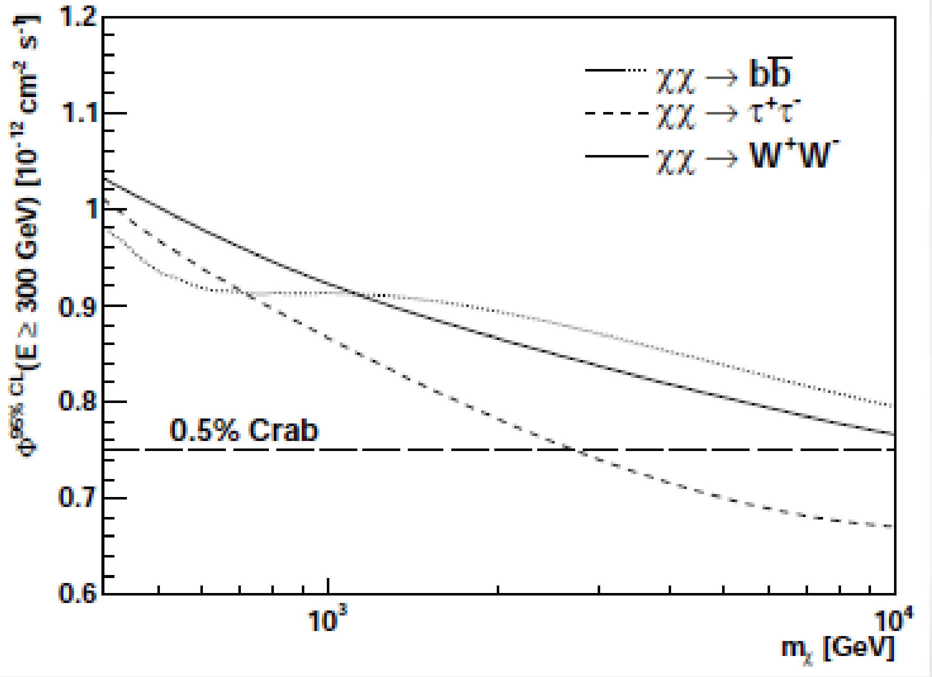
1% of Crab Nebula integrated flux above 300 GeV is 1.5×10^{-12} ph/(cm^2 s)

UL with DM gamma-ray spectra

- 3 different branching ratios considered (simulated with PYTHIA) :
  - b-bbar (generic quark spectrum)
  - W+W-
  - tau+tau-

Annihilation (Decay) spectra





(x=2E/mχ)

DM bounds

- 2 scenarios considered :
  - Annihilating DM

$$\frac{d\Phi_\gamma}{dE}(\Delta\Omega, E) = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2\,m_\chi^2}\frac{dN_\gamma}{dE} \times \bar{J}(\Delta\Omega)$$

Einasto profile*

$$\bar{J}(\Delta\Omega) = \int_{\Delta\Omega} d\Omega \int_{s_{min}}^{s_{max}} \rho_\chi^2(r[s])ds$$

$$\bar{J}(\Delta\Omega) = 7.7 \times 10^{18}\,\mathrm{GeV}^{-2}\,\mathrm{cm}^{-5}\,\mathrm{sr}$$

  - Decaying DM

$$\langle\sigma v\rangle/2\,m_\chi^2 \to \Gamma/m_\chi,\ \text{where } \Gamma = \tau^{-1}$$

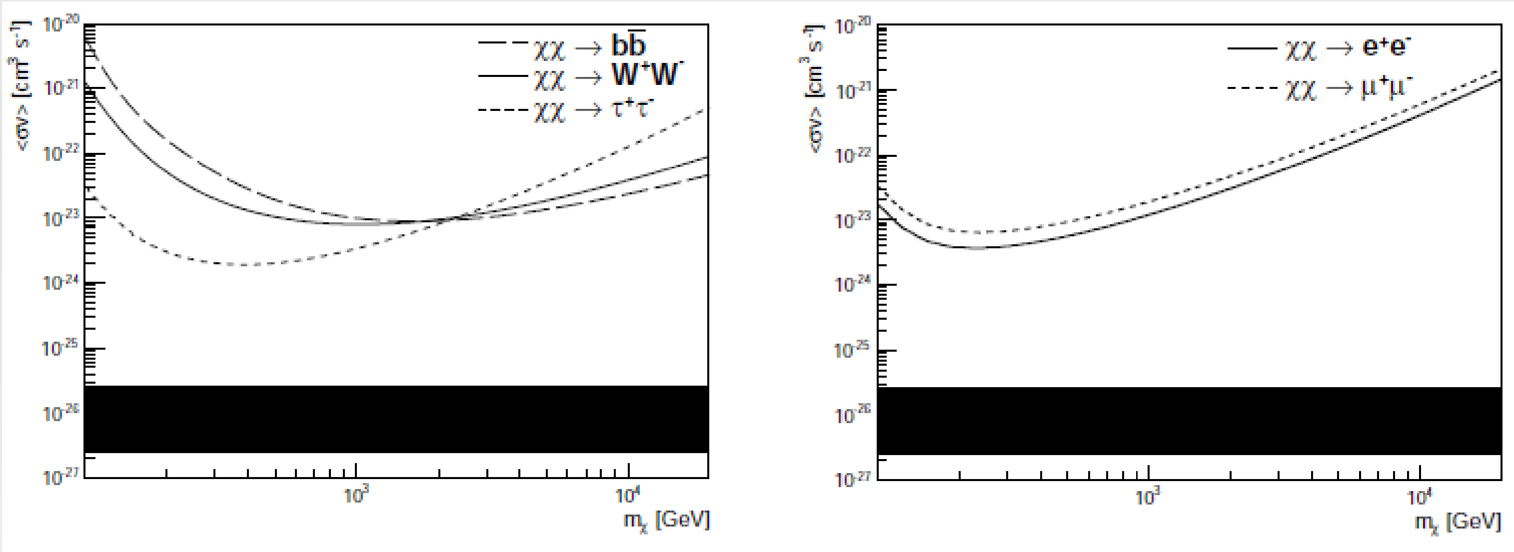
$$\rho_\chi^2 \to \rho_\chi$$

$$\bar{J}(\Delta\Omega) = 2.6 \times 10^{17}\,\mathrm{GeV}\,\mathrm{cm}^{-2}\,\mathrm{sr}$$

* claim that systematic uncertainties on the astrophysical factor are <10

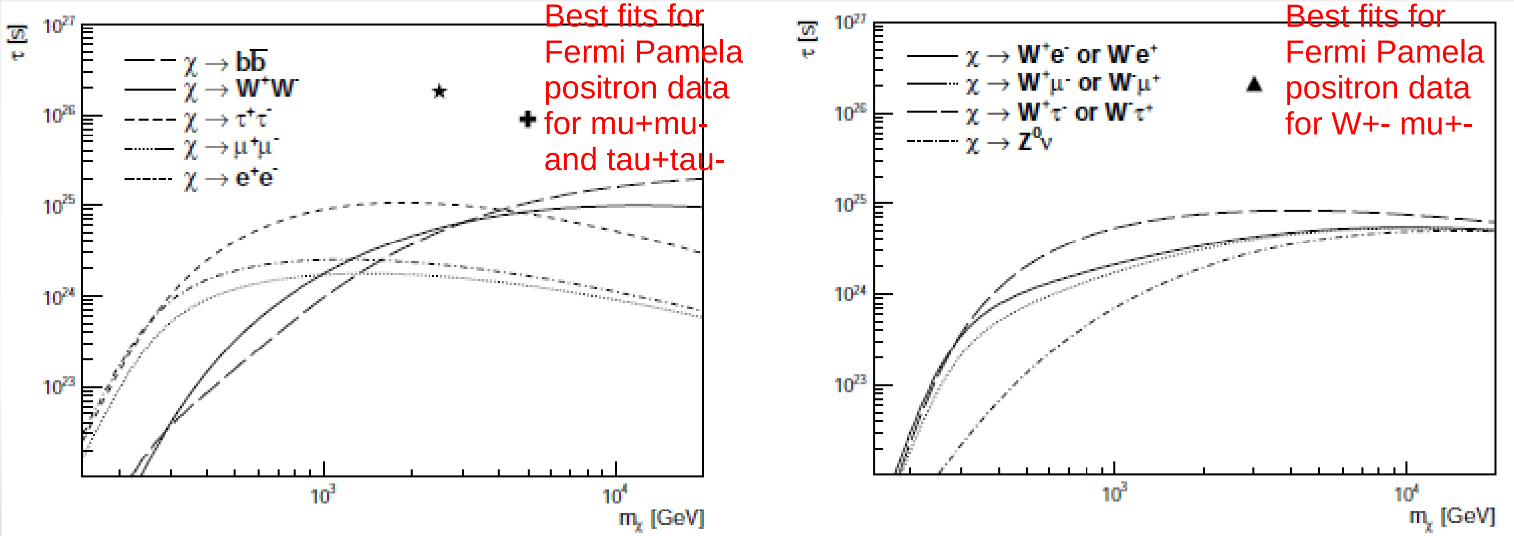
DM bounds (ctd)

- UL on annihilation cross-section



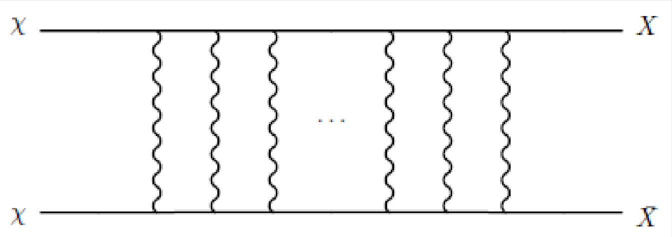
WMAP constrains for thearmally produced WIMPs

- LL on the decay lifetime



Constraints on Sommerfeld enhancement and boost factor

Sommerfeld enhancement :
multiple exchange of gauge boson ϕ before DM annihilation $\rightarrow$ ladder Feynman diagram $\rightarrow$ 'natural' boost factor



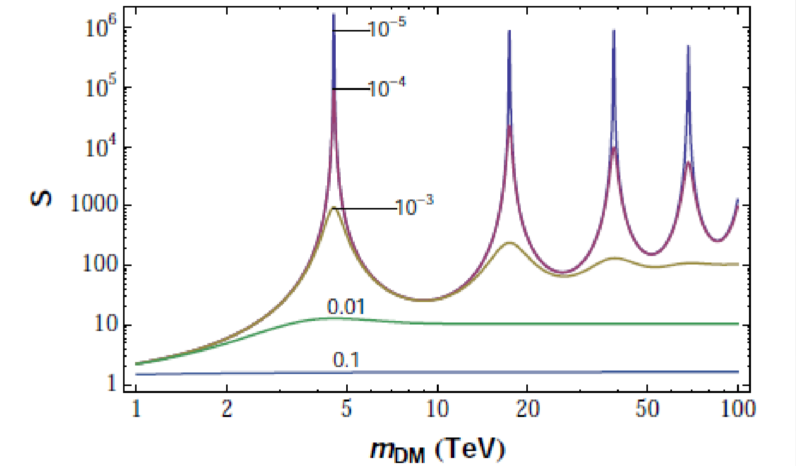
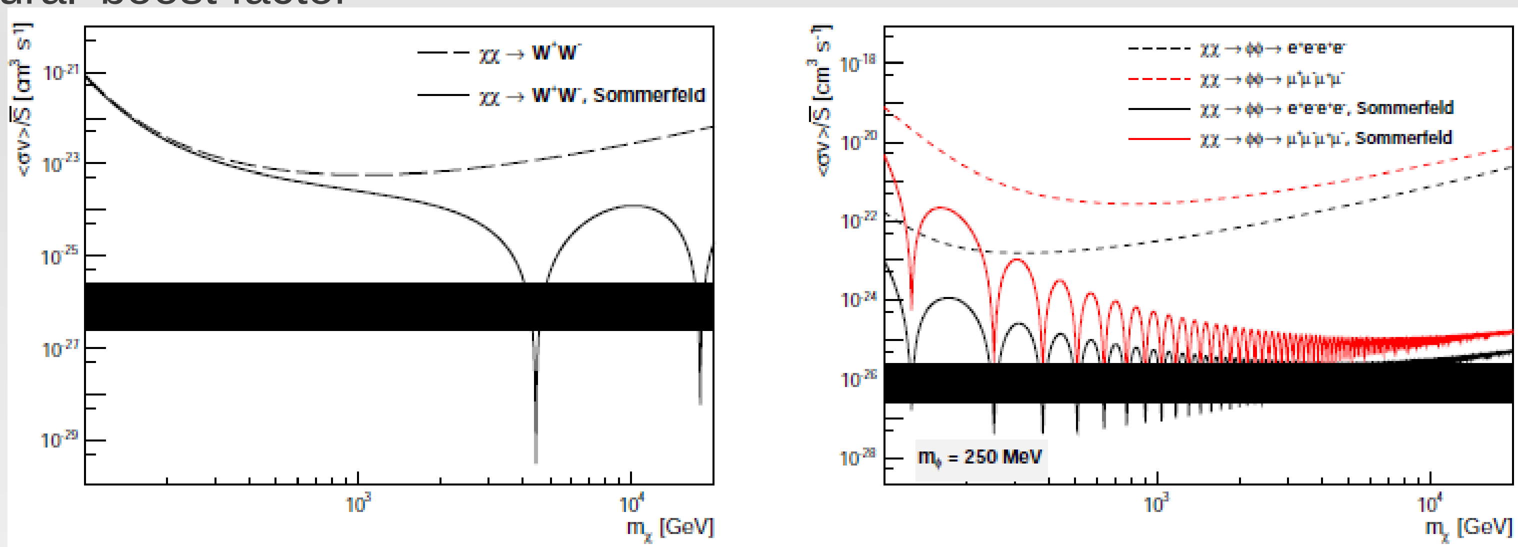


FIG. 2: Sommerfeld enhancement S as a function of the dark matter particle mass m, for different values of the particle velocity. Going from bottom to top $\beta = 10^{-1}, 10^{-2}, 10^{-3}, 10^{-4}, 10^{-5}$.

Constraints on Sommerfeld enhancement and boost factor

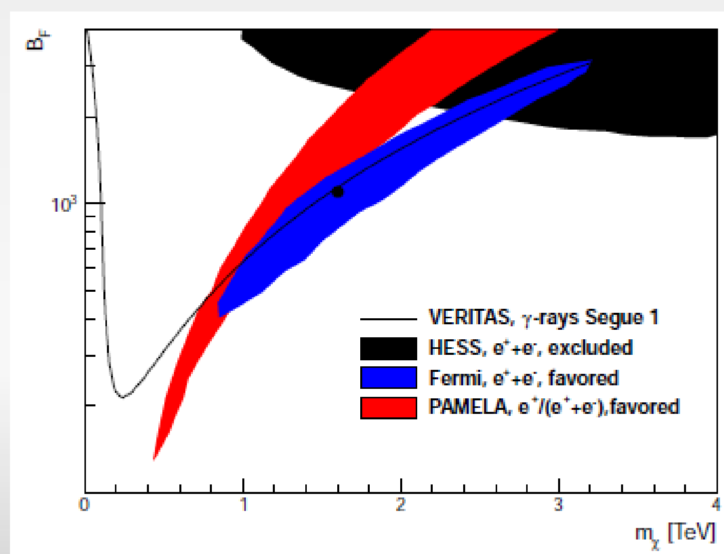
Sommerfeld enhancement :
multiple exchange of gauge boson ϕ before DM annihilation $\rightarrow$ ladder Feynman diagram
$\rightarrow$ 'natural' boost factor

Wino-like model
$\phi = Z^0$



Ad hoc model
ϕ is a light scalar field decaying into letons with a mass ~ 1GeV

Model-independant* boost factor constraint



*still 100% annihilation into μ+μ- with $<\sigma v>=3\times10^{-26}$ cm^3/s assumed